JOURNAL OF AGRICULTURAL RESEARCH

VOL. 74 WASHINGTON, D. C., FEBRUARY 15, 1947 No. 4

THE RESPONSE OF HYBRID POPLAR AND OTHER FOREST TREE SPECIES TO FERTILIZER AND LIME TREATMENT IN CONCRETE SOIL FRAMES[1]

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INTRODUCTION

A set of 48 concrete-walled soil frames or bins which had been used 7 years for a wide variety of crops was turned over to the writer in the spring of 1934 for use in forest tree studies. The fertility level varied greatly as a result of the previous treatments, and crop responses had been most striking. The frames provided opportunity for experimenting with trees in what were essentially pot culture tests, and the object of the study was to observe the behavior of the trees under reasonably controlled conditions where presumably the only variable was the nutrient supply. Special emphasis is placed on the results with hybrid poplar inasmuch as the stock came from a single clone of known genetic history.

LITERATURE REVIEW

The literature on fertilization of nursery stock and plantations is quite voluminous and in many cases contradictory. Much of the work done abroad is inapplicable to conditions in this country. The apparent discrepancies in the responses reported may be ascribed to differences in species, source of seed or planting stock, kinds of fertilizers, method and rate of application, weather conditions, fertility level, and physical condition of the soil. There is ample evidence that red pine is relatively unresponsive to fertilizers (*9*, *20*).[2] Results on spruce obtained by the writer (unpublished) and others frequently lack agreement, but the consensus of opinion is that the requirements of Norway, white, and probably red spruce are higher than those of red or Scotch pine.

In the report of a special committee of the New York Section of the Society of American Foresters (*7*), it was stated that most hardwood and shrub species require better soils and are less able to withstand weed and grass competition than the average conifer. Red oak can grow almost anywhere once it is established, but sugar maple requires a fairly good site.

[1] Received for publication January 3, 1946.

[2] Italic numbers in parentheses refer to Literature Cited, p. 131.

There is reasonably good evidence (*4*, *8*, *11*) that growth of black locust and green ash is increased by fertilizers high in phosphorus and low in nitrogen and potassium. Cummings (*3*) found that growth differences with white ash were small but that there was a generally beneficial effect from the highest application of nitrogen. Yellow poplar showed no significant response to any treatment.

Very little work has been done on the nutritional requirements of hybrid poplars. Schreiner (*16*) found that they are particularly sensitive to inimical environmental conditions, and that the beneficial effect of sod, turned under, far exceeded that of fertilizers, even where comparatively large quantities of nitrogen were used.

EXPERIMENTAL PROCEDURE

SOIL FRAMES, TREATMENTS, AND PREVIOUS HISTORY

The trees were grown in 3 sets of 16 frames, each frame being approximately 2 feet square (0.0001 acre) and 2 feet deep, without artificial bottoms, resting directly on the natural subsoil. They were constructed and filled in 1927, with Cheshire loam.[3]

Treatments were 0, P, K, PK, N, NP, NK, and NPK, and the same repeated with lime.[4] The initial liming in 1927 increased the soil pH from 5.0 to 7.5 on the limed series. By 1939 it had dropped to 5.6, and the soils of the acid series averaged 4.75. Sufficient limestone was then added to raise the pH of the acid series to 5.2 and that of the limed series to 6.6. Beginning with 1939, calcium acetate was included with all nitrogen treatments in order to lessen the danger of calcium deficiency. Details of the treatments and the cropping history are given in table 1, and the arrangement of the frames is shown in figure 1.

Choice of fertilizer materials was prompted by the desire to avoid accummulating nonessential ions, such as sodium, chlorine, etc., in the soil. The soil test data given in table 2 show the fertility status of the soil. It will be noted that all soils receiving nitrogen were more acid because of the nitric acid formed and the absence of bases to neutralize it. Nitrate nitrogen tests are not listed because they almost invariably showed low values as a result of the rapid utilization of nitrates by the growing crops. Phosphorus and potassium differences were extreme because of the long period of treatment. Calcium was increased greatly by lime. In all cases where the treatment included N but left out K, the Ca content was conspicuously low because Ca unites with nitric acid in the soil to form calcium nitrate which is either absorbed by the roots or leached downward. The same condition applies to magnesium but to a lesser degree. With the inclusion of potassium in the treatment, this role of neutralizer is shared by the potassium, hence the drain on calcium and

[3] Reddish-brown upland soil derived from Triassic sandstone and shale glacial till. The original profile consisted of 6 to 8 inches of dark-brown loam (A), overlying a slightly reddish yellow-brown sandy loam subsoil (B), which at 24 inches, graded into a coarse, stony, reddish glacial till (C). Only the A and B horizons were used to fill the frames, the soil fromeach horizon being thoroughly mixed separately and placed in the frames in the same relative positions as in the field.

[4] 0=check; P=phosphorus; K=potassium; N=nitrogen; L=lime.

TABLE 1.—*Fertilizer and lime treatments given and cropping history of soil frames used in experiments*

Growing season	Materials and rate of application			Crops		
	Element or lime	Carrier	Pounds per acre	West series (frames 1–16)	Middle series (frames 17–32)	East series (frames 33–48)
1927–1933	N	Urea	100 N	Celery, Sweet corn, Spinach—tomatoes—rye, Lettuce—peppers—rye, Dahlias, Havana seed tobacco, Barley—buckwheat—rye		
	P	H_3PO_4	200 P_2O_5			
	K	K acetate	100 K_2O			
	L[1]	$CaCO_3$	8,000 $CaCO_3$			
	(Identical all 7 yrs. except for lime)					
1934–1936	Same as above; half in spring, half in fall			Red pine	Red oak	Sugar maple
1937–1938	Same as 1934–36			White ash	White ash	Sugar maple
1939	N	Urea	100 N	White ash	White ash	Norway spruce (1–0 stock)
		Ca acetate	30 Ca			
	P	$CaH_4(PO_4)_2$	200 P_2O_5			
	K	KCl	100 K_2O			
	Mg[2]	$MgSO_4$	60 MgO			
	L[3]	$CaCO_3$	Varied			
	(Half in spring, half in fall)					
1940	N	Uramon	25 N	White spruce (seed)		
		Ca acetate	30 Ca			
	(Spring only)					
1941	N	Urea	25 N	White spruce (continuation of growth started in 1940)		
		Ca acetate	15 Ca			
	P	$CaH_4(PO_4)_2$	50 P_2O_5			
	K	KCl	25 K_2O			
	Mg[2]	$MgSO_4$	25 MgO			
	(Spring only)					
1942	Same as in 1939 except that lime was omitted, and only the spring application was made, half in April, half in June			Two millet green manure crops turned under followed by winter cover crop of oats.		
1943	Same as in 1939, omitting lime and magnesium (Applied in April and June)			Hybrid poplar cuttings		

[1] Lime applied only twice—1927 and 1939.
[2] Magnesium applied to all frames.
[3] Enough $CaCO_3$ added to bring soils to uniform pH—5.2 for acid series, 6.6 for limed series. Applied in spring only.

TABLE 2.—*Average values of soil acidity and quick tests in soils after treatments with different fertilizer elements and lime*

[Universal quick-test method (*12*)]

Treatment[1]	pH	Pounds per acre of—					Treatment[1]	pH	Pounds per acre of—				
		P	K	Ca	Mg	Al			P	K	Ca	Mg	Al
0	4.98	15	90	600	15	450	L	6.06	30	140	3,400	60	80
P	4.87	120	100	530	25	310	LP	5.79	150	100	3,370	80	50
PK	5.16	120	535	760	50	230	LPK	6.09	200	650	3,100	90	25
K	5.29	15	555	780	30	275	LK	6.28	30	610	3,460	60	30
NK	4.60	15	195	270	15	500	LNK	5.50	20	575	2,170	40	200
N	4.39	20	85	260	10	510	LN	5.19	20	120	1,470	25	270
NP	4.35	160	85	270	10	400	LNP	5.25	150	140	1,890	40	185
NPK	4.59	160	200	430	15	375	LNPK	5.43	150	575	2,500	60	125
Average	[2]4.78	78	231	480	21	381	Average	[2]5.70	94	364	2,670	57	121

[1] L=lime.
[2] According to Dr. C. I. Bliss, Connecticut station biometrician, the arithmetic mean of the pH values comes nearer to describing the middle of the group than does the pH calculated from the mean of the hydrogen-ion concentrations.

magnesium is lessened. Aluminum tended to vary inversely with calcium and the pH values.

It should be emphasized that the soil differences existing during the time when the trees occupied the ground and the effects of these differences on tree growth were due in part to the residual effect of previous treatments and in part to the current treatment.

FIGURE 1.—View of soil frames, showing rye cover crop just prior to spading under in preparation for planting red pine, red oak, and sugar maple. Upper set—west series; middle set—middle series; lower set—east series. Photographed April 21, 1934.

Unfortunately, treatments were not randomized, and close proximity to greenhouses and a 2½-story building caused partial shade and an unevenness of snow cover resulting from interference with air currents. The earlier work reported in part in previous publications (*9*, *10*) was more or less exploratory in nature and hence was not always replicated. It will be presented very briefly, most emphasis being placed on the hybrid poplars.

KIND AND SOURCE OF STOCK

Red pine (*Pinus resinosa* Ait.) hand-selected 2–0 stock, obtained from a local nursery, was planted 30 trees to the frame, and 2 years later thinned to 9 to the frame. Southern red oak (*Quercus falcata* Michx.) and sugar maple (*Acer saccharum* Marshall) 6- to 12-inch seedling whips were obtained from Tennessee and planted 5 to the frame. The oaks were cut back to 3 inches, and after 2 years, thinned to 1 tree per frame. At the end of 4 years the maples were thinned to 3 per frame. One-year-old white ash (*Fraxinus americana* L.) seedlings from a Connecticut State nursery were planted on 2 series, 5 trees to the frame. Norway spruce (*Picea excelsa* Link) 1–0 selected seedlings, from a State nursery, were planted 30 to the frame. White

spruce (*Picea glauca* (Moench) Voss) seed, procured from a dealer, was sown at the rate of 6.25 gm. to the frame.

The hybrid poplar cuttings used in this work were from nursery stock grown at Williamstown, Mass.[5] All the cuttings came from a single hybrid clone designated as OP–8. The parentage of this hybrid is *Populus nigra* L. (female) × *P. laurifolia* Ledeb. (male). The use of dormant, graded cuttings of a single clone eliminates most of the initial variation (due to size and inherent variability) to be expected from seedling stock (*15*).

The cuttings were 12 inches long and graded as to diameter. Total weight of the six cuttings planted in each frame ranged from 65 to 77 gm. with an average of 71.3 gm. Two buds were left above ground in all cases. The first application of fertilizer was made April 2; the cuttings were planted April 5, with five replacements on May 18 from extra cuttings which had been started with the others. The second application of fertilizer was made June 14. Water was applied twice during the unusually dry weather of late summer.

On August 17, one tree of average size was removed from each frame and plant tissue tests were run on the petioles. Green and dry weights were obtained on the bare stems. On October 11, petioles were removed from the upper third or half of each tree (except 18 trees saved for subsequent rooting tests) and submitted to plant tissue tests. On October 29–30, all remaining leaves were stripped off, the whips cut off, and green and dry weights obtained. The 18 trees previously mentioned were weighed green and then placed in cold storage. In January 1944, cuttings from these were set in moist sand to determine whether previous treatment had affected rooting and sprouting ability.

METHODS OF ANALYSIS

Chemical analysis of oak, maple, and ash leaves were made by the usual laboratory methods[6] on dried and ground leaves including petioles. In the case of the poplars, plant tissue tests were run on the fresh petioles by a modification of the method proposed by Wolf (*21*), which in turn is an adaptation of Morgan's Universal Soil Testing System (*12*), to permit readings by means of the photelometer.

Soil tests were made by Morgan's method (*12*), except for the October 1943 sampling, when a modification of the Wolf (*21*) method was used.

RESULTS WITH PINE, OAK, MAPLE, ASH, AND SPRUCE

RED PINE

Detailed data pertaining to the results with red pine have already been presented (*9*), and will be summarized only briefly here. At the end of the third season differences due to treatment were relatively small (table 3). Growth was definitely poorer with lime in seven cases out of eight. Potassium appears to have been beneficial, but

[5] The cuttings were obtained through the courtesy of Dr. E. J. Schreiner, of the Northeastern Forest Experiment Station.

[6] Total nitrogen by the Gunning method modified to include nitrates. Ash constituents by the perchloric acid digestion of Gieseking, Snider, and Getz (*6*).

weights taken on trees removed the preceding year during a thinning operation (data not given) showed no such indication. In six cases out of eight, the root-top ratio was lower on the limed soils (averages, limed 0.190; unlimed 0.209), and varied among the individual treatments from 0.166 to 0.241. Data obtained more recently in nursery studies of other conifers have been very inconsistent with respect to root-top ratios. No chemical analyses were made of the red pines.

TABLE 3.—*Response of red pine and southern red oak to soil treatment with fertilizer elements and lime*

RED PINE

Soil with—	Average dry weight per tree (tops and roots)[1]								Average
	0	P	PK	K	NK	N	NP	NPK	
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
No lime	40.9	36.3	37.8	50.4	49.1	45.8	45.7	44.2	43.8
Lime	35.5	37.0	33.0	42.9	46.3	40.4	39.6	38.8	39.2
Average	38.2	36.7	35.4	46.7	47.7	43.1	42.7	41.5	.....
Relative	100	96	93	122	125	113	112	109	.....

SOUTHERN RED OAK

Soil with—	Average green weight per tree (tops only)[2]								Average
No lime	157	216	172	220	213	348	133	246	213
Lime	136	129	203	139	145	140	276	251	177
Average	147	173	188	180	179	244	205	249	.....
Relative	100	118	128	122	122	166	140	170	.....

[1] Based on 8-10 trees per frame, April 1937.
[2] Based on 4 or 3 trees in 1936, 1 tree in 1937.

SOUTHERN RED OAK

Typical of hardwoods, the individual red oak trees varied greatly in rate of growth. Obviously the small number of trees in each frame and the absence of replication seriously lower the validity of the data (table 3). However, certain trends may be noted: (1) growth averaged less on the limed soils, and (2), there was a general, if inconsistent, response to treatment. It is believed that the low value for NP and the very high value for N, both without lime, were decidely abnormal and cannot be attributed to the treatments.

Chemical analysis of the leaves collected in the fall of 1935 showed relatively small differences. The data are summarized in table 4. The lower values for silica on the limed soils indicate that the calcium either repressed the absorption of silica or took its place to a certain extent. The same can be said in explanation of the slightly lower potassium content where lime was used. Phosphorus treatment resulted in a somewhat higher phosphorus content. In the absence

of phosphorus, silica absorption was increased on the unlimed soils. Potassium applied to the soil was not reflected in any increase in potassium in the leaves.

TABLE 4.—*Composition of southern red oak leaves collected in the fall of 1935 from trees in limed and unlimed soil*

[Average values for 8 treatments]

Constituent	Without lime		With lime	
	Average	Range	Average	Range
	Percent	*Percent*	*Percent*	*Percent*
Ash	4.89	4.32–5.19	4.85	4.39–5.25
N	1.98	1.85–2.17	2.04	1.86–2.17
P	.14	.13–.16	.16	.14–.17
SiO_2	.60	.49–.72	.44	.33–.55
K	1.11	.96–1.24	1.00	.92–1.12
Ca	1.03	.84–1.16	1.20	.98–1.47

SUGAR MAPLE

Like the oaks, the sugar maples were decidedly lacking in uniformity of growth. The data in table 5 show a positive response to lime in

TABLE 5.—*Response of sugar maple to soil treatments with fertilizer elements and lime*

[Average green weight per tree, exclusive of roots; based on 3 trees, 1939]

Soil with—	0	P	PK	K	NK	N	NP	NPK	Average
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
No lime	160	467	280	185	384	190	214	180	257
Lime	254	407	203	372	462	402	330	316	343
Average	207	437	242	279	423	296	272	248	.....
Relative	100	211	117	134	204	143	131	120	.....

most cases. In general, growth was increased by fertilizer treatment, but no attempt is made to explain why the largest trees were those receiving the P and NK treatments, and next to the smallest those receiving the NPK treatment.

Leaf samples were collected and analyzed separately in 1935, 1936, and 1938. Detailed data are given in table 6. The difference between years was highly significant for ash, N, K, and Ca; differences between treatments were all significant except those for nitrogen. Variations due to applied nitrogen were significant only for nitrogen, those due to lime were highly significant for ash and calcium, but not for phosphorus. The ash content was significantly affected also by phosphorus (directly) and potassium (inversely); potassium by the potassium treatment (directly), and calcium by the potassium treatment (inversely) as well as by lime (directly).

TABLE 6.—*Composition of sugar maple leaves from trees in soils treated with different fertilizer elements and lime*

MEANS OF 1935, 1936, AND 1938 ANALYSES

Treatment [1]	Ash	N	P	SiO_2	K	Ca
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	6.65	1.64	0.117	1.87	0.71	1.38
P	7.57	1.69	.153	2.19	.77	1.62
PK	6.89	1.68	.186	2.23	.91	1.25
K	6.63	1.66	.124	1.94	.94	1.31
NK	6.84	1.74	.150	1.94	1.09	1.24
N	7.31	1.79	.144	2.27	.88	1.34
NP	7.70	1.67	.136	2.28	.82	1.56
NPK	6.60	1.73	.140	2.26	1.00	.97
Average	7.03	1.70	.144	2.12	.89	1.33
L	7.76	1.55	.125	1.88	.68	1.85
LP	8.43	1.66	.224	2.45	.79	1.76
LPK	7.98	1.64	.256	2.01	.97	1.64
LK	7.55	1.74	.152	2.15	.95	1.46
LNK	7.08	1.66	.127	1.76	.91	1.61
LN	7.47	1.81	.132	2.01	.74	1.78
LNP	7.94	1.85	.143	2.27	.76	1.95
LNPK	7.03	1.74	.193	1.71	.98	1.57
Average	7.66	1.71	.169	2.03	.85	1.70

MEANS OF ALL TREATMENTS

Year:						
1935	6.47	1.94	.161	2.14	.93	1.48
1936	7.63	1.59	.156	1.96	.81	1.45
1938	7.93	1.59	.152	2.17	.87	1.62

SIGNIFICANCE OF VARIATIONS DUE TO YEARS AND TREATMENTS [2]

Years	**	**	—	—	**	**
Treatments	**	—	**	*	**	**
N	—	*	—	—	—	—
L	**	—	—	—	—	**
P	*	—	**	ϕ	—	—
K	**	—	—	—	**	**
NP	—	—	*	—	—	—

[1] L=lime.

[2] **Highly significant; *significant; ϕalmost significant; —not significant.

WHITE ASH

As white ash was grown on two series, the data were subjected to statistical analysis. From table 7, it is seen that there were significant differences between treatments, and that variations due to nitrogen and to lime were highly significant. On the basis of average values, NP produced the largest trees, but statistically the effects of P were not significant.

The means of the 1938 and 1939 leaf analyses are presented in table 8. Oddly enough, the leaves from the limed frames were practically no higher in calcium than those without lime, but their calcium content was significantly affected by N directly, and by K inversely. Nitrogen applications resulted in a higher concentration of nitrogen in the leaves on the unlimed plots only. The phosphorus content was increased by the phosphorus treatment, particularly on the plots without nitrogen. Plants receiving phosphorus had a tendency to take up more SiO_2 than those without phosphorus. The higher potassium concentration from the K-treated frames was almost significant.

Magnesium was affected, directly by the lime and inversely by the potassium treatments.

During the 1938 growing season it was noticed that a considerable number of leaves were definitely crinkled and others had a dark mottled appearance, neither of which could be correlated with soil treatment. Analysis of such leaves shows (bottom of table 8) that

TABLE 7.—*Response of white ash trees to soil treatment with fertilizer elements and lime*

[Average green weight per tree, exclusive of roots, at the end of the third growing season, 1939; based on 5 trees per frame]

Soil with—	Series	0	P	PK	K	NK	N	NP	NPK	Total
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
No lime	West	152	127	125	136	121	128	184	150	1, 123
	Middle	73	129	90	83	193	123	157	134	982
Total		225	256	215	219	314	251	341	284	2, 105
Lime	West	94	134	127	128	223	163	225	272	1, 366
	Middle	84	118	91	80	213	230	275	201	1, 292
Total		178	252	218	208	436	393	500	473	2, 658

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	*F*	Source of variation	Degrees of freedom	*F*
Between series	1	1. 46	K	1	<1
Between treatments	15	[1] 5. 23	PK	1	2. 64
N	1	[1] 47. 11	NK	1	<1
L	1	[1] 9. 66	NP	1	<1
P	1	3. 13	LN	1	[1] 14. 23

[1] Highly significant.

TABLE 8.—*Composition of white ash leaves from trees in soils treated with different fertilizer elements and lime*

MEANS OF 1938 AND 1939 ANALYSES

Treatment [1]	Ash	N	P	SiO_2	K	Ca	Mg
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	5. 87	1. 14	0. 127	0. 605	1. 49	1. 19	0. 126
P	6. 39	1. 05	. 213	. 715	1. 60	1. 05	. 092
PK	6. 79	1. 16	. 236	. 925	1. 67	. 93	. 099
K	6. 02	1. 09	. 115	. 575	1. 67	1. 05	. 074
NK	6. 49	1. 58	. 139	. 605	1. 83	1. 11	. 061
N	6. 86	1. 39	. 115	. 585	1. 81	1. 27	. 069
NP	7. 15	1. 43	. 171	. 800	1. 80	1. 23	. 095
NPK	6. 79	1. 30	. 174	. 695	1. 94	. 93	. 071
Average	6. 55	1. 27	. 161	. 688	1. 73	1. 09	. 086
Lime	6. 64	1. 19	. 153	. 570	1. 63	1. 15	. 151
LP	7. 11	1. 21	. 252	. 590	1. 61	1. 13	. 143
LPK	6. 69	1. 43	. 301	. 530	1. 65	. 93	. 121
LK	6. 87	1. 21	. 173	. 500	1. 75	1. 01	. 089
LNK	7. 31	1. 17	. 124	. 495	1. 87	1. 19	. 091
LN	6. 35	1. 18	. 127	. 555	1. 37	1. 21	. 142
LNP	6. 39	1. 21	. 175	. 565	1. 27	1. 31	. 150
LNPK	6. 61	1. 37	. 172	. 575	1. 71	1. 15	. 105
Average	6. 75	1. 25	. 185	. 547	1. 61	1. 13	. 124

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TABLE 8.—*Composition of white ash leaves from trees in soils treated with different fertilizer elements and lime*—Continued

MEANS OF ALL TREATMENTS

Treatment [1]	Ash	N	P	SiO_2	K	Ca	Mg
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Year:							
1938	7.10	1.44	0.185	0.551	1.73	1.04	0.088
1939	6.19	1.07	.161	.683	1.61	1.19	.122

SIGNIFICANCE OF VARIATIONS DUE TO YEARS AND TREATMENTS [2]

Years	**	**	*	**	*	*	**
Treatments	θ	—	**	—	**	—	**
N	—	—	**	—	—	**	—
L	—	—	θ	**	—	—	**
P	—	—	**	*	—	—	—
K	—	—	—	—	θ	**	**

SPECIAL SAMPLES 1938 ONLY

Normal leaves	6.35	1.99	0.193	0.377	1.51	1.08	0.115
Crinkled leaves	8.59	1.52	.186	.575	1.62	1.42	.099
Dark mottled leaves	7.55	1.31	.166	.563	1.86	.97	.072

[1] L=lime.
[2] **Highly significant; *significant; θ almost significant; — not significant.

the abnormal leaves were lower in N, P, and Mg, and higher in SiO_2 and K than the normal. Whether these differences are significant is not known.

NORWAY SPRUCE

Data obtained at the end of one season (table 9) showed that growth of Norway spruce was less on the limed soils in 5 cases out of 8. Growth was poorest in the K-treated frames. The highest proportion of roots to tops was found in the NP frame, and the lowest in the K frame. These data are based on an average of 23 plants per frame, with 1 frame, NPK, having only 8 plants. No significance is attached to these differences; the data are given primarily for record.

TABLE 9.—*Response of Norway spruce to soil treatment with fertilizer elements and lime, one season only, 1939*

[Number of plants per frame ranged from 8 to 30, with an average of 23]

Soil with—	Average dry weight of whole plant (tops and roots)								Average
	0	P	PK	K	NK	N	NP	NPK	
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
No lime	0.67	0.84	0.80	0.40	0.70	0.36	0.68	0.65	0.637
Lime	.52	.51	.46	.45	.61	.65	.63	.70	.566
Average	.595	.675	.63	.425	.655	.505	.655	.675	.601
	Root-top ratio								
No lime	0.500	0.526	0.597	0.373	0.703	0.787	0.823	0.573	0.610
Lime	.598	.649	.554	.678	.669	.765	.716	.631	.657
Average	.549	.587	.575	.523	.686	.771	.769	.602	.633

WHITE SPRUCE

Full replication permitted statistical analysis of the data on white spruce, although the experimental design was systematic rather than randomized. Survival was extremely variable owing to a combination of factors most of which were independent of treatment. The data in table 10 show that lime had no effect on survival.

The size of plants, based on average green weight of the whole tree, including roots, at the end of the second year was smaller on the limed series. Among individual treatments, LK and LNK produced the smallest trees, and PK, NP, NPK, and LNPK the largest. Statistical analysis (table 11) reveals that differences due to L, P, and PK were

TABLE 10.—*Number of white spruce plants per frame and average green weight per tree*

Soil with—	Series	Number of plants per frame								Total
		0	P	PK	K	NK	N	NP	NPK	
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
No lime	West	54	1	38	51	208	214	188	131	885
	Middle	127	403	267	165	228	170	296	340	1,996
	East	246	364	253	225	235	136	236	261	1,956
Total		427	768	558	441	671	520	720	732	4,837
Lime	West	63	111	35	159	186	147	304	183	1,188
	Middle	388	141	225	0	61	215	281	314	1,625
	East	239	242	281	304	335	254	216	180	2,051
Total		690	494	541	463	582	616	801	677	4,864
Grand total		1,117	1,262	1,099	904	1,253	1,136	1,521	1,409	9,701
		Average green weight per tree (tops and roots)								
No lime	West	.73	.80	1.59	.83	.91	1.15	1.80	2.05	9.86
	Middle	1.18	1.27	1.51	.93	1.16	1.57	1.55	1.71	10.88
	East	.74	.95	1.23	.71	1.19	1.00	.71	.79	7.32
Total		2.65	3.02	4.33	2.47	3.26	3.72	4.06	4.55	28.06
Lime	West	.49	.72	1.14	.37	.27	.32	1.22	1.42	5.95
	Middle	.70	1.48	1.20	0	.20	.95	1.22	1.68	7.43
	East	.46	.69	.73	.61	.42	.73	.64	1.01	5.29
Total		1.65	2.89	3.07	.98	.89	2.00	3.08	4.11	18.67
Grand total		4.30	5.91	7.40	3.45	4.15	5.72	7.14	8.66	46.73
Relative		100	137	172	80	97	133	166	201	

TABLE 11.—*Analysis of variance for average green weight per tree (white spruce), corrected by covariance for differences in stand*

[Based on data in table 10]

Variation due to—	Degrees of freedom	Mean square (reduced $[Y^2]$)	Observed F
Blocks	2	0.607690	[1] 7.98
Lime	1	1.848082	[1] 24.27
Nitrogen	1	.258040	3.38
Phosphorus	1	2.202934	[1] 28.93
Potassium	1	.019411	<1
Phosphorus × potassium	1	.657545	[1] 8.64
Lime × phosphorus	1	.385563	5.06
Interactions	9	.038517	<1
Regression of yield on stand	1	.282745	3.71
Blocks × treatments (error)	29	.076136	
Total	47		

[1] Significant.

significant, and that LP would undoubtedly have been significant had the treatments been randomized. The analysis of variance was corrected by co-variance for differences in stand.

There was considerable variation in the root-top ratios on the different frames but only those differences due to lime were significant (average without lime 0.586; with lime 0.633).

No analyses were made of the white spruce plants.

RESULTS WITH HYBRID POPLAR

GROWTH

The oven-dry (73° C.) weights of the trees, minus leaves and original cuttings, are given in table 12. Growth differences were quite pronounced, with nitrogen causing greatest response, lime next, and then phosphorus. Combinations of two or more elements were generally more effective than any one element alone. The greatest average increase was 275 percent. Potassium was inconsistent in its effect, and in many cases growth was less with it than without. Similar behavior was observed in spruce. The significance of these differences is shown in table 13.

TABLE 12.—*Average dry weight per tree of hybrid poplars treated with different fertilizer elements and lime* [1]

Block	O	P	PK	K	NK	N	NP	NPK	Total
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	
West	13.9	14.2	14.7	13.6	31.7	57.9	49.5	49.7	245.2
Middle	14.3	22.8	12.8	12.7	25.6	21.7	[2] 35.5	38.1	183.5
East	15.8	22.1	13.3	15.5	25.7	31.0	30.7	36.3	190.4
Average	14.7	19.7	13.6	13.9	27.7	36.9	38.6	41.4	619.1
Relative	100	134	92	94	188	250	263	282	.....
	L	LP	LPK	LK	LNK	LN	LNP	LNPK	Total
West	17.3	11.8	17.8	16.6	41.2	43.0	63.8	53.4	262.9
Middle	19.4	23.2	21.4	20.1	59.3	62.5	59.7	53.5	319.1
East	15.9	22.7	20.6	15.1	32.0	37.1	41.3	58.5	243.2
Average	16.9	19.2	20.0	17.3	44.2	47.5	54.9	55.1	825.2
Relative	115	131	136	118	300	323	374	375	.....

[1] L=lime.
[2] 1 tree; in all other cases each figure is the average of 5 or 6 trees.

TABLE 13.—*Analysis of variance for average dry weight per tree of hybrid poplars*

[Based on data in table 12]

Variation due to—	Degrees of freedom	Mean square	Observed *F*
Blocks	2	107.724	1.60
Treatments	15	687.341	[2] 10.19
Blocks × Treatments (error)	30	67.422	.....
Total	47	266.983	.....
Lime × nitrogen	1	395.027	[1] 5.86
Lime	1	884.942	[2] 13.13
Nitrogen	1	8,350.325	[2] 123.85
Phosphorus	1	354.797	[1] 5.26
Potassium	1	43.892	<1.0
First order interaction (except LN)	5	31.430	<1.0
Second and third order interactions	5	24.796	<1.0

[1] Significant at 5-percent level.
[2] Significant at 1-percent level.

Differences in leaf color were quite apparent also. The leaves of all trees receiving nitrogen were a darker green than those without it.

When the trees were removed at the end of the season it was found that the original cuttings had increased in diameter, the increase being greatest in those frames in which treatment resulted in the largest whip growth. A few representative data from this study are given in table 14. It will be recalled that all of the cuttings were of the same size when planted in the spring. The larger trees possessed longer and thicker roots also, but no measurements were made.

TABLE 14.—*Measurements showing relation between growth of whip and diameter growth of original cutting when trees were removed from frames at the end of the growing season* [1]

Treatment	Average dry weight of whips	Average diameter of cutting	Average weight of cutting when partially dried
	Grains	*Millimeters*	*Grams*
K	13.9	9.32	13.08
0	14.7	9.60	13.15
N	36.9	12.36	22.07
NPK	41.4	13.70	27.16

[1] All cuttings were the same size when planted in the spring.

EFFECT OF TREATMENT ON SUBSEQUENT ROOTING

Cuttings from the base, middle, and upper portions of the 18 whips held over in cold storage from the previous fall were planted in moist sand on January 31. Thirty-three days later, March 4, the shoots and roots were removed from the original cuttings and the dry weights of each obtained. Both shoot growth and root development (table 15) were largest on the base cuttings and smallest on the top cuttings. Because the previous treatments had exerted such a positive effect on the size of cuttings, it is difficult to separate the effect of treatment per se on rooting or sprouting from that of size alone. However, the ratio of both shoot and root weight to cutting weight tended to decrease with increase in size of cutting.

In the handling of the cuttings, a good many buds dropped off in spite of the care exercised to prevent it. It was observed that the cuttings which had received nitrogen the previous season lost their buds much more readily than the others. Confirmation of this behavior is necessary before conclusions can be drawn. Obviously the cuttings without buds failed to sprout or sprouted only weakly. Data from such cuttings were omitted when calculating the means in table 15.

TABLE 15.—*Average amount of shoot and root growth, and ratio of shoot and root weight to cutting weight, in relation to position on whip*

Position on whip	Average weight of—			Ratio of shoot weight to cutting weight	Ratio of root weight to cutting weight
	Cuttings	Shoots	Roots		
	Grams	*Grams*	*Grams*		
Top	2.11	0.44	0.025	0.211	0.0119
Middle	4.51	.63	.043	.149	.0104
Base	8.09	1.09	.074	.140	.0102

COMPOSITION OF PETIOLES AS INDICATED BY PLANT TISSUE TESTS

The results of plant tissue tests made August 17 on the petioles from all treatments, and those of October 11 on six of the treatments are given in figures 2 and 3, together with the yield and soil test data. Figure 2 shows that the application of phosphorus definitely increased the phosphorus content of the soil in all cases, but the concentration in the petioles was increased only in those cases where growth was limited by lack of nitrogen. Potassium treatment increased the amount of available potassium in the soil; in the petioles the increases occurred chiefly on the limed plots.

Calcium was more abundant in the limed soils, of course, but the increase in the petioles was slight. Other treatments had relatively little effect on the calcium content. Magnesium in the soil was slightly greater in the limed frames but otherwise showed little variation. In the petioles magnesium was highest in the N and NP treatments; potassium appeared to repress assimilation of magnesium. Recent studies by Boynton and Burrell (1) have shown that magnesium deficiency in McIntosh apple trees may be induced by potash fertilization.

The phosphorus relationships shown in figure 3 are essentially like those in figure 2 as far as they go. However, the phosphorus content of the petioles for the PK treatment was only a fraction of what it was on August 17. Apparently, this difference is a characteristic seasonal one. The potassium concentration in the petioles was somewhat lower in October but otherwise the relationships are similar to what they were in August. Calcium and magnesium were generally higher in October. Tissue tests showed no nitrate nitrogen in the petioles.

DISCUSSION

The relatively slight response of red pine to the treatments is not surprising considering the low requirements of that species. Norway spruce is generally considered as having somewhat higher nutritive requirements, but the limited data in this particular experiment are of little value in supporting that view. There is no question as to the response of white spruce to phosphorus, either alone or with potassium, and of the adverse effect of lime.

Among the hardwoods, southern red oak was adversely affected by lime but was apparently benefited generally by fertilizers. Sugar maple, white ash, and hybrid poplar responded readily to lime and fertilizer. The poplars as well as the spruces seemed to be adversely affected by potassium when used alone. In this connection Eriksson (*5*) reports that in some soils, particularly those relatively rich in sesquioxides, phosphorus fixation is increased through the application of K salts, especially in muriate form, and crop yields are reduced, except at high levels of P. Even where yields were not affected, the P content of the plant (barley and oats) was lower. Eriksson's theory is that potassium restricts hydrolysis of the amphoteric soil complexes and increases the formation and precipitation of Fe and Al phosphates. If this theory is correct it might explain the poor growth in the K-treated frames of Norway and white spruce. There is no evidence that potassium treatment had any consistent effect on the phosphorus content of the oak, maple, and ash leaves or the hybrid poplar petioles.

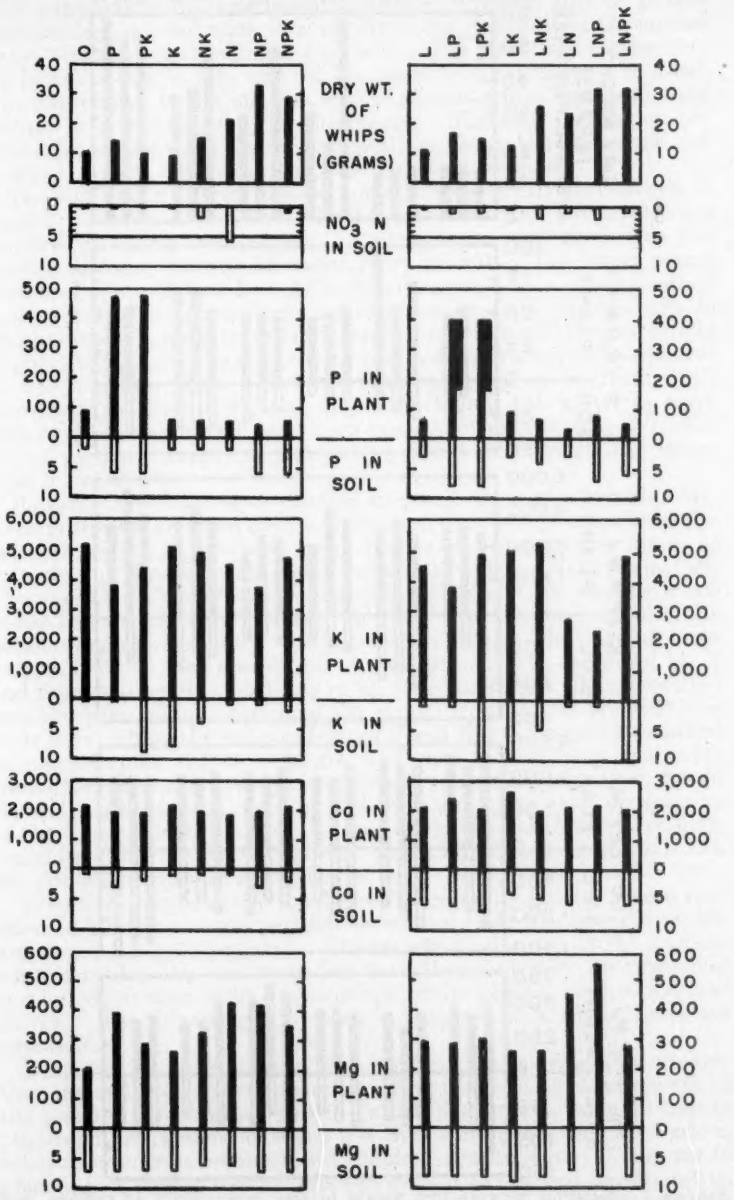
O P PK K NK N NP NPK
L LP LPK LK LNK LN LNP LNPK
DRY WT. OF WHIPS (GRAMS)
NO_3 N IN SOIL
P IN PLANT
P IN SOIL
K IN PLANT
K IN SOIL
Ca IN PLANT
Ca IN SOIL
Mg IN PLANT
Mg IN SOIL

FIGURE 2.—Relation between dry weight of trees, composition of petioles, and available nutrients in soil (Morgan's quick test method). Sampled August 17. Plant petiole data given in parts per million; soil test data on arbitrary scale of 1 to 10—1 being very low and 10 very high.

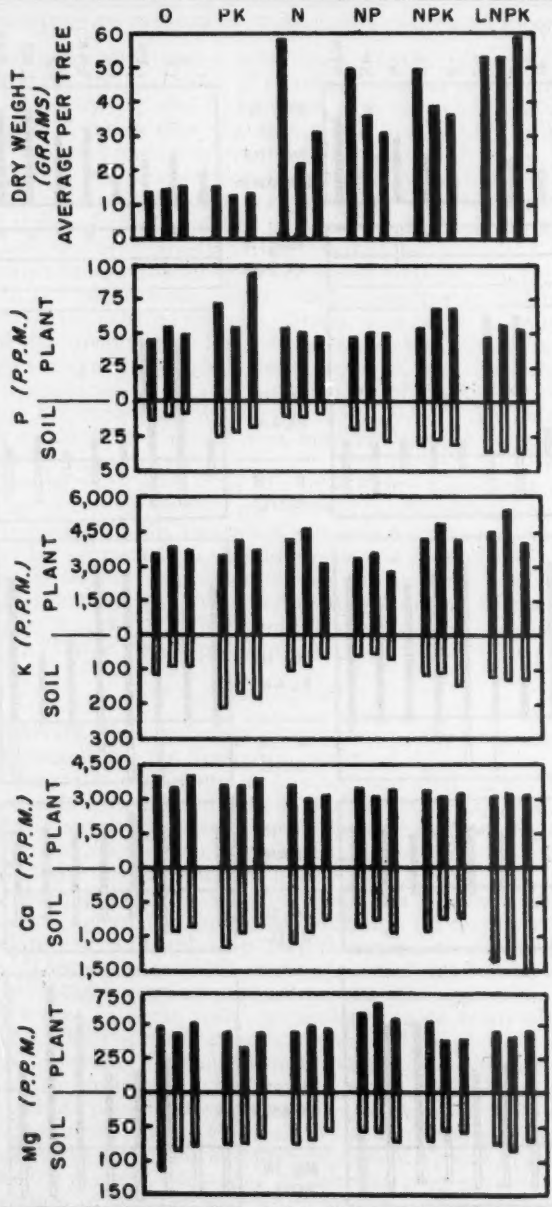

FIGURE 3.—Relation between dry weight of tree, composition of petioles, and available nutrients in the soil (Wolf method). Sampled October 11. The hree bars in each treatment represent the three blocks or sets of frames.

In considering the relationships between growth, leaf or petiole composition, and soil tests, it is apparent that for most of the species tested nitrogen was the limiting element. The phosphorus content of the leaves of oak, maple, and ash increased with the increase in available phosphorus in the soil, but similar increases from potassium and calcium were evident only in the maples. The only correlation observed between growth and soil composition was in the case of red oak in which growth decreased with increase of soil calcium.

The soil under hybrid poplars contained some nitrate nitrogen in August but none in October. In August, the P and PK treatments resulted in luxury consumption of phosphorus, and there was not enough nitrogen present for satisfactory growth. The larger plants produced when P and N were included resulted in a dilution effect in the plant, although soil tests indicated an ample supply of available phosphorus. It is quite probable, however, that a still greater supply of phosphorus would have given a higher concentration of phosphorus in the petioles. This has been the experience of Scarseth (*14*), Carolus (*2*), Ulrich (*19*), and others, including the writer in work with table beets, spinach, and snap beans (not published). Whether or not a greater supply of phosphorus would have resulted in larger trees is not known.

Potash without nitrogen resulted in a high concentration of potassium in the soil but had only a moderate effect on the amount in the petioles. With N, however, more K was absorbed by the plant, as indicated by the somewhat lower soil test but higher plant tissue test. The available Ca content of the soil in relation to the various treatments has already been discussed (p. —). The calcium content of the petioles decreased slightly with increase in yield. The data on magnesium indicate that absorption of that element was enhanced by N and repressed by K. Süchting et al. (*18*) found that liming resulted in a lower potassium content of the plant. Němec (*13*) found this to be true (a) where the soil was high in P and K and practically neutral in reaction, and (b) on soils low in P and K and quite acid. He found that lime increased K absorption on soils (a) high in P, low in K, and nearly neutral, and (b) high in P and quite acid, irrespective of the K content of the soil. In this study the data show very little correlation, on the whole, between available calcium in the soil and the potassium content of the leaves.

Variation between individual trees is generally greater where root space is limited and competition severe, as when five or six trees are growing in a 2-by-2 foot area. The variation exhibited by the poplars, while considerable, was much less than that shown by the preceding species which were ordinary seedlings whose genetic history was unknown. The advantages of using cuttings from a single clone are apparent.

Response to treatment by the poplars was considerably greater than it was by the previous species owing to the more rapid growth of the poplars. This rapid growth, which makes it a valuable tree in pulpwood production, as shade tree and windbreak, and for various other uses such as excelsior and cellulose manufacture (*17*), seems to place it in a class with farm crops in respect to nutrient requirements. There is no question but that a fast-growing tree is a more suitable indicator plant for forest trees than a fast-growing, shallow-rooted

annual like corn, for instance. Can it be assumed, however, that any fast-growing plant can indicate the needs of a slow-growing one even though they may be similar in all respects except rate of growth? For example, the requirements of oak, being low, permit the tree to live on nutrients which become available slowly in the soil—too slow for poplars. For that reason, oaks grow satisfactorily on relatively poor soil without benefit of fertilizer treatment; and if fertilizers are used, the response is only moderate. Perhaps the chief advantage of a fast-growing species as an indicator plant is to show what is needed but not how much.

While the response (or lack of it) shown by experiments of this kind are indicative of the requirements of the species in question, it is recognized that the magnitude of response observed in pot or tank cultures is not generally obtained in the field. Restriction of root space tends to intensify the differences resulting from treatment. This is particularly true with trees and other plants with large root systems. Nevertheless, the experiment shows that most species are benefited by a relatively high fertility level; that some are favored by lime and some are not, and that of the three main plant food elements, potassium is the least apt to be limiting.

Another angle of the nutrition problem—the extraordinarily favorable effect of humus materials, composts, and sod which have been reported in the literature (*16*)—was not touched upon in this investigation. It is, however, a profitable field for future studies in our quest for the answer to the all important question, How can the success of hardwood plantings in open fields be assured?

SUMMARY

A set of 48 concrete-walled frames, each 1/10,000 acre in size and containing Cheshire loam, was used to determine the growth response to lime and fertilizer of red pine, southern red oak, sugar maple, Norway spruce, white ash, and white spruce seedlings, and single clone hybrid poplar cuttings. Treatments consisted of N, P, and K, alone and in various combinations, with and without lime.

Soil tests show that the treatments resulted in very marked differences in the fertility level and acidity of the soil.

Red pine made less growth in the limed frames; differences due to other treatments were relatively small. Southern red oak was likewise adversely affected by lime. Response to other treatments was inconsistent but appeared to be greater on the nitrogen-treated soil.

Norway spruce, like red pine and oak, was adversely affected by lime.

Lime had an adverse effect also on white spruce, but P and PK were beneficial and the results were statistically significant. Root-top ratios were higher with lime than without.

The concentration of the major elements in the leaves (or petioles) of the hardwoods was increased, in general, by treatment with those elements. In oak the SiO_2 content was considerably lower and the phosphorus higher on the limed soils. In maple, the ash content was affected significantly by the lime, P, and K treatments. In white ash, the phosphorus content was affected by N as well as by P; silica was influenced by lime and P; calcium by N and K; and magnesium by

lime and K. In both maple and ash, a high concentration of K in the soil resulted in a lower concentration of calcium in the leaves.

Growth of hybrid poplar was more uniform and the response to treatment considerably greater than it was with the other species. Nitrogen caused the greatest response, lime next, and phosphorus third. Potassium was inconsistent in its effect.

The original cuttings increased in size during the growing season more or less in proportion to the growth of the whips.

Subsequent rooting and sprouting of cuttings taken at the end of the season from whips produced during the summer tended to be more or less proportional to the size of the cuttings. The effect of treatment per se could not be isolated from the effect of cutting size.

In the petioles the phosphorus concentration was, in general, inversely proportional to the growth of the tree, but potassium was increased more or less irrespective of growth. Calcium increased but slightly. Magnesium absorption was highest in the NP frames and appeared to be repressed by K.

The principal facts brought out in this work are that (a) the pine, spruces, and red oak were adversely affected by lime, but sugar maple, white ash, and hybrid poplar were benefited by it; (b) response to nitrogen and phosphorus was low in the case of red pine and Norway spruce, but medium to high for all other species; (c) response to potassium, in spite of the low level of available potassium in the untreated soil, was negative in most cases. The rapid growth of hybrid poplars would seem to make them ideal for use in nutritional studies of forest trees, but the writer is of the opinion that the requirements of this or any other fast-growing tree may be quite different from those of a slow grower, hence results obtained with the former should not be applied to the latter without due caution.

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THE EFFECT OF SOURCE OF LITTLE BLUESTEM GRASS SEED ON GROWTH, ADAPTATION, AND USE IN REVEGETATION SEEDINGS[1]

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INTRODUCTION

The revegetation of cultivated land and depleted ranges to grass in the Great Plains during the past 10 years has required large amounts of grass seed. Under certain conditions of low rainfall and erosion, the native species were found to be better adapted than introduced species but seed supplies were not readily available. Methods of harvesting seed of grasses from native prairies have been developed, but the production of such seed in the Great Plains is erratic because of fluctuating climatic conditions, and the movement of seed supplies from other regions of the United States to meet the demands has not proved feasible.

When seed of native grasses from different sources was brought together in Soil Conservation Service nurseries to determine their relative value and adaptation for revegetation seedings, it was found that great differences existed within certain species in respect to time of flowering, seed and forage production, winter hardiness, and other factors important to the revegetation program. This situation prompted a study of little bluestem (*Andropogon scoparius* Michx.) from 16 different sources, as shown in column 2 of table 1.

REVIEW OF LITERATURE

Variations in plant characteristics and behavior of *Andropogon furcatus* (*5*),[3] *Bouteloua curtipendula* (*2*, *7*), *B. gracilis* (*2*, *3*, *8*, *9*), *Panicum virgatum* (*1*), and many other species from different sources have been discussed or photographs published by several individuals. These plant variates have been designated by various names such as biotypes (*2*), isolates (*6*), geographical strains (*7*), and ecotypes (*11*, *12*). The writer considers Turesson's (*11*, *12*) designation of ecotype to be the most appropriate for the plant accessions discussed in this paper. Turesson proposed the term "ecotype" for an ecological unit

[1] Received for publication November 20, 1945.

[2] The author gratefully acknowledges the assistance received from members of the Kansas Agricultural Experiment Station during the course of this study.

[3] Italic numbers in parentheses refer to Literature Cited, p. 142.

TABLE 1.—*Data obtained at Manhattan, Kans., Soil Conservation Service nursery for 16 ecotypes of little bluestem (Andropogon scoparius) including accession number, source, flowering date (actual and theoretical), caryopsis count, dry weight per plant, and height per plant*

Accession No.	Source	Actual flowering date	Theoretical[1] flowering date[2]	Caryopsis count				Dry weight of plants			Height of plants			
				1940	1941	1942	Average	1940	1941	Average	1940	1941	1942	Average
				Percent	*Percent*	*Percent*	*Percent*	*Grams*	*Grams*	*Grams*	*Inches*	*Inches*	*Inches*	*Inches*
KG570	Towner, N. Dak	June 20	July 6	22.0	8.6	4.5	11.7	67	193	130	24.7	20.3	26.5	23.8
KG181	Cheyenne, Wyo	June 21	June 11	39.6	12.6	14.0	22.1	216	387	302	28.5	27.1	31.7	29.1
KG1	O'Neill, Nebr	July 18	July 26	20.0	11.0	24.3	18.4	214	406	310	32.6	34.7	39.8	35.7
KG538	Moorhead, Iowa	July 26	Aug. 8	15.0	9.3	23.7	16.0	181	455	318	31.5	27.6	38.9	32.7
KG473	Eldorado, Kans	Aug. 18	Aug. 17	32.0	20.3	39.7	30.7	376	735	556	42.9	41.5	52.1	45.5
KG116	Colony, Kans	Aug. 26	Aug. 23	32.0	26.0	22.0	26.7	379	558	469	43.4	39.5	52.5	45.1
KG1037	Manhattan, Kans	Aug. 18	Aug. 19	44.7	18.3	23.0	28.7	397	780	589	43.9	41.4	51.3	45.5
KG480	do	Aug. 19	do	29.0	19.3	27.3	25.2	441	719	580	43.1	44.5	50.8	46.1
KG6	Guthrie, Okla	Aug. 30	Sept. 4	27.6	29.3	25.7	27.5	407	775	591	45.7	44.5	52.9	47.7
KG1043	Orlando, Okla	Aug. 24	Aug. 29	52.6	27.3	23.0	34.3	406	695	551	44.9	44.3	59.2	49.5
KG753	Ardmore, Okla	Aug. 29	Sept. 8	45.0	19.3	12.7	25.7	380	816	598	47.0	51.1	60.8	53.0
KG1085	Woodward, Okla	Aug. 13	Aug. 19	43.3	26.6	25.0	31.6	296	573	435	41.0	42.6	50.5	44.7
KG1108	Chapel Hill, N. C	Oct. 24	Sept. 21	19.6	.3	.3	6.7	472	1,179	826	48.5	56.6	64.6	56.6
KG640	Douglas, Ariz	July 26	Aug. 11	33.3	12.0	6.0	17.1	110	312	211	37.6	37.0	38.3	37.6
KG725	Edna, Tex		Oct. 9	0	0	0	0	311	897	604	40.8	53.8	56.4	50.3
KG531	Vernon, Tex	Sept 10	Sept. 1	44.6	11.6	11.0	22.4	889	2,237	1,563	57.5	57.3	69.1	61.3
Average				31.3	15.7	17.6	21.6	346	732	540	40.9	41.5	49.7	44.0

[1] Correlation of theoretical with actual flowering date: $r=0.9819$.
[2] Determined by Hopkins' bioclimatic law (4).

arising as a result of the genotypical responses of an ecospecies to a particular habitat.

Although significant morphological differences were found in biotypes of *Panicum virgatum*, as reported by Nielsen (*6*), and *Bouteloua gracilis* and *B. curtipendula*, as reported by Fults (*2*), neither of these investigators found any regional segregation of races on the basis of chromosome number. The chromosome complements could not be correlated with the biotypes. Chromosome determinations were not made in this study.

METHODS

Seedlings were started in the greenhouse in March and transplanted to the field in May 1939. The soil was alluvial fine sandy loam of good fertility. A plant was set every 30 inches in the row and the rows were 30 inches apart. Twenty seedlings were transplanted for each ecotype, but survival was not good and only 208 plants remained for study. Complete detailed measurements were not taken for more than 10 plants of any one ecotype on account of the time required.

Since the plants did not become well established until 1940, data were not recorded in 1939. In 1940, 1941, and 1942, the seed for caryopsis counts was stripped from the plants by hand as soon as it was mature. The date that each plant came into full bloom was recorded in 1941. The dry weight of individual plants was obtained for 1940 and 1941 at the end of the growing season in October. The height of each plant was taken at the end of the growing season in 1940, 1941, and 1942.

Rod-square plots of eight ecotypes listed in table 6 were field-seeded in May 1938. One series of these plots was seeded broadcast. A second series was seeded in 14-inch rows. The soil was similar to that used for the individual plant study. A good stand emerged with both methods of seeding in early June. Observations were made until 1942.

EXPERIMENTAL RESULTS AND DISCUSSION

FLOWERING DATE

The most northern ecotypes, those from North Dakota and Wyoming, flowered in late June, whereas the more southern ones, from Texas and North Carolina, did not flower until September or October (table 1, column 3). Analysis of variance shows a highly significant difference between the time the various ecotypes came into full bloom (table 2). Statistical calculations in this paper were computed according to methods of Snedecor (*10*).

TABLE 2.—*Analysis of variance for flowering time of 208 little bluestem plants representing 15 ecotypes, 1941*

Source of variation	Degrees of freedom	Sum of squares	Mean square	*F*
Total	207	188,887		
Between ecotypes	14	157,890	11,277.9	70.22*
Within ecotypes	193	30,997	160.6	

*Exceeds *F* for *P* of 0.01 with appropriate degrees of freedom.

The actual flowering dates of the ecotypes are very close to the theoretical dates that might be expected by the application of Hopkins' bioclimatic law (*4*). The date, August 19, which was the actual date for the Manhattan, Kans., ecotype (accession No. KG480) was used as the base date. The latitude, longitude, and altitude of the place in which the seed originated were compared for each ecotype with similar data for Manhattan, Kans. Four days for each degree of latitude, 1 day for each degree of longitude, and 1 day for each 100 feet in altitude were added or subtracted from the Manhattan values for these three constants. The values obtained by these calculations were converted into the number of days earlier or later than the flowering date for the Manhattan ecotype (August 19) and given as the theoretical dates in column 4 of table 1. A highly significant correlation of +0.9819 was found to exist between the actual flowering date and these theoretical flowering dates based on Hopkins' bioclimatic law.

All ecotypes were observed to start growth at approximately the same time in the spring. The number of days after June 15 that each ecotype was in full flower is given in table 3.

TABLE 3.—*Average number of days after June 15 that little bluestem ecotypes from 15 different sources were in full flower at the Manhattan, Kans., Soil Conservation Service grass nursery, 1941*

Accession No.	Source	Days after June 15 (means)[1]
KG570	Towner, N. Dak	4.63
KG181	Cheyenne, Wyo	5.81
KG1	O'Neill, Nebr	32.64
KG538	Moorhead, Iowa	39.82
KG640	Douglas, Ariz	41.00
KG1085	Woodward, Okla	58.94
KG1037	Manhattan, Kans	63.50
KG473	Eldorado, Kans	63.65
KG480	Manhattan, Kans	65.05
KG1043	Orlando, Okla	69.60
KG116	Colony, Kans	71.70
KG753	Ardmore, Okla	74.89
KG6	Guthrie, Okla	75.79
KG531	Vernon, Tex	87.33
KG1108	Chapel Hill, N. C	131.22

[1] Least significant mean difference=10.74.

SEED PRODUCTION

The weight of seed produced by each plant was not determined. Caryopsis counts were made for each ecotype giving the percent of florets containing mature caryopses. These data are given in columns 5, 6, 7, and 8 of table 1. The two earliest ecotypes, from North Dakota and Wyoming, were below the yearly averages of all sources in 1941 and 1942. Early flowering frequently coincides with periods of hot winds unfavorable to seed production. Late August and early September flowering of the Kansas and Oklahoma ecotypes favor a good seed set. The late September or October flowering of the Texas and North Carolina ecotypes resulted in frost injury in 1941 and 1942. The Edna, Tex., ecotype was so late in developing inflorescenses that seed was not produced in any of the 3 years.

DRY WEIGHT OF PLANTS

The lowest dry weight per plant was produced by the northern ecotypes from North Dakota (fig. 1, *A*), Wyoming, and Nebraska

(columns 9, 10, and 11, table 1). These ecotypes did not appear to grow much more than the others in early season, and they stopped growth at their flowering time about midsummer. The local (fig. 1, *B*) and southern ecotypes, on the other hand, continued growing until late summer. Some of the southern ecotypes had fresh green leaves at frost time, whereas leaves of the northern ecotypes had begun to dry by midsummer and were completely dry by late summer. The most vigorous and productive ecotype was from Vernon, Tex. (fig. 1, *C*). The nine plants ranking highest in dry weight (fig. 2) were from this ecotype. Plant breeders engaged in developing superior strains may be able to use such plants for introducing vigor and high yield. The difference between ecotypes was highly significant for each of the 2 years that weights were taken, 1940 and 1941, as shown in table 4.

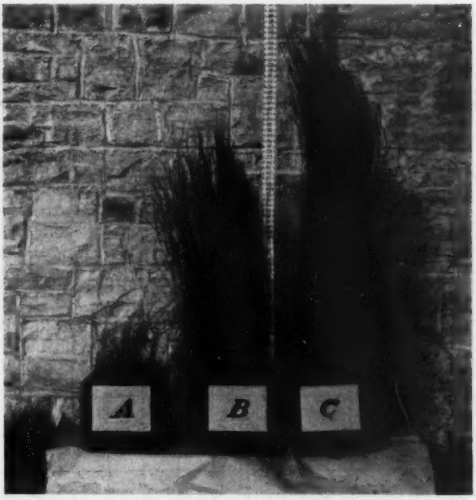

FIGURE 1.—Individual plants of little bluestem representing three different ecotypes grown at Soil Conservation Service nursery, Manhattan, Kans., 1942: *A*, KG570, Towner, N. Dak.; *B*, KG473, Eldorado, Kans.; *C*, KG531, Vernon, Tex.

TABLE 4.—*Analysis of variance of dry weight per plant for 16 ecotypes of little bluestem, 1940 and 1941*

Source of variation	Degrees of freedom	Sum of squares	Mean square	*F*
		1940 data		
Total	217	11,104,213		
Between ecotypes	15	6,469,989	431,333	18.80*
Within ecotypes	202	4,634,224	22,942	
		1941 data		
Total	142	40,136,922		
Between ecotypes	15	28,354,960	1,890,331	20.38*
Within ecotypes	127	11,781,962	92,771	

*Exceeds *F* for *P* of 0.01 with appropriate degrees of freedom.

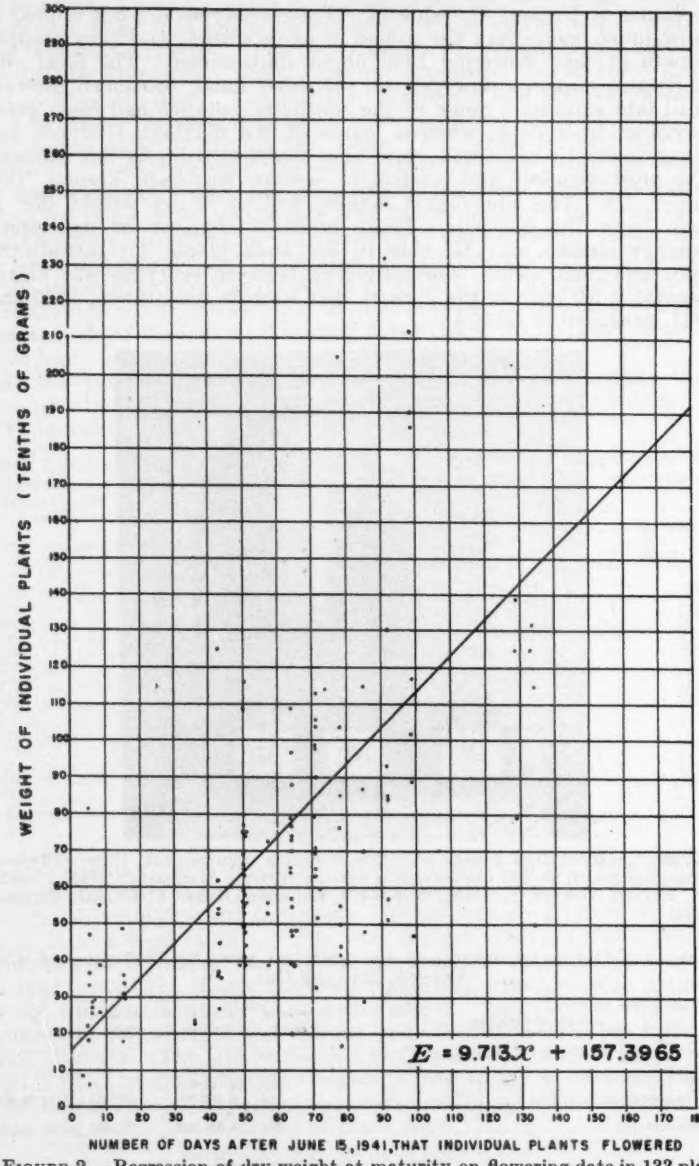
WEIGHT OF INDIVIDUAL PLANTS (TENTHS OF GRAMS)
NUMBER OF DAYS AFTER JUNE 15, 1941, THAT INDIVIDUAL PLANTS FLOWERED
E = 9.713x + 157.3965

FIGURE 2.—Regression of dry weight at maturity on flowering date in 133 plants of little bluestem grown at the Manhattan, Kans., Soil Conservation Service nursery in 1941.

HEIGHT OF PLANT

The North Dakota and Wyoming ecotypes averaged less than 30 inches for the 3-year period (table 1). The Nebraska and Iowa ecotypes were about 35 inches tall, whereas those from Kansas and Oklahoma ranged from an average of 44.7 to 53.0 inches for the 3 years. The greater altitude of Douglas, Ariz., apparently produced an effect similar to northerliness, as was shown by the fact that the Douglas ecotype had a height of only 37.6 inches, flowered earlier, and had a lower dry weight than other southern ecotypes. The Vernon, Tex., ecotype was the tallest, the average height being 61.3 inches, with one plant in 1942 having the maximum height of 78 inches. The relative height of northern, local, and southern ecotypes is shown in figure 1. The difference in height of the various ecotypes was found to be highly significant by analysis of variance (table 5).

TABLE 5.—*Analysis of variance for height of 16 ecotypes of little bluestem, 1940 to 1942, inclusive*

Source of variation	Degrees of freedom	Sum of squares	Mean square	*F*
		1940 data		
Total	219	17,971		
Between ecotypes	15	13,249	883.27	38.15*
Within ecotypes	204	4,722	23.15	
		1941 data		
Total	214	24,656		
Between ecotypes	15	18,658	1,244	41.47*
Within ecotypes	199	5,998	30	
		1942 data		
Total	211	26,738		
Between ecotypes	15	21,857	1,457	58.28*
Within ecotypes	196	4,881	25	

*Exceeds *F* for *P* of 0.01 with appropriate degrees of freedom.

FLOWERING DATE AND WEIGHT OF PLANT

Flowering time usually marks the end of vigorous growth for most grasses. Therefore, early flowering of warm season grasses reduces the length of time in which the plants produce the best grazing and lowers the total yield of dry weight per plant in plants left to the end of the growing season. To determine the effect of flowering date upon dry weight of plant at maturity the regression coefficient was determined for 133 plants in 1941 as $E=9.713X+157.3965$, as given in figure 2. Correlation of these two characters was $+0.5775$, which is highly significant for the appropriate degrees of freedom.

WINTER HARDINESS

The individual plants in this test were sufficiently favored by location to permit all the ecotypes to survive the winter. The susceptibility of certain ecotypes to winter injury was found when different ecotypes were compared in rod-square plots. Unfortunately, all of the same ecotypes could not be tested in both rod-square plots and as individual plants because of limited seed supply and facilities. The

rod-square plots did not afford enough replications for statistical analysis. However, the differences between certain ecotypes were sufficiently great, as shown in figures 3 and 4, to justify the conclusion that all ecotypes should be carefully tested for winter survival before they are moved very far northward for large scale plantings. Table 6 gives the percent of winter injury for eight ecotypes tested in 1940–41.

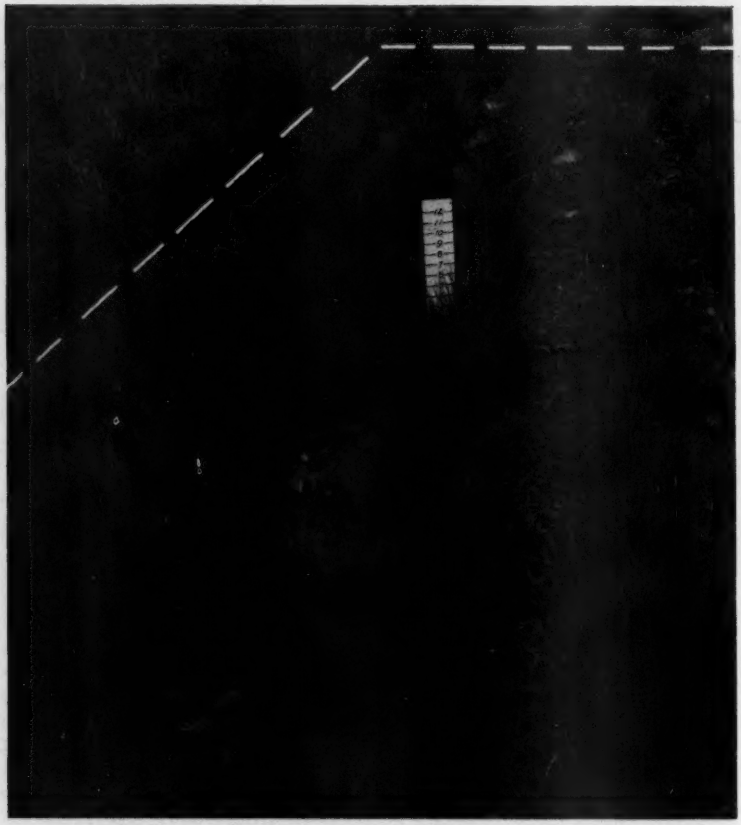

FIGURE 3.—Little bluestem ecotype, origin Manhattan, Kans., grown in rod-square plot Soil Conservation Service nursery at Manhattan, showing good spring growth as a result of complete winter hardiness. Photographed May 10, 1941.

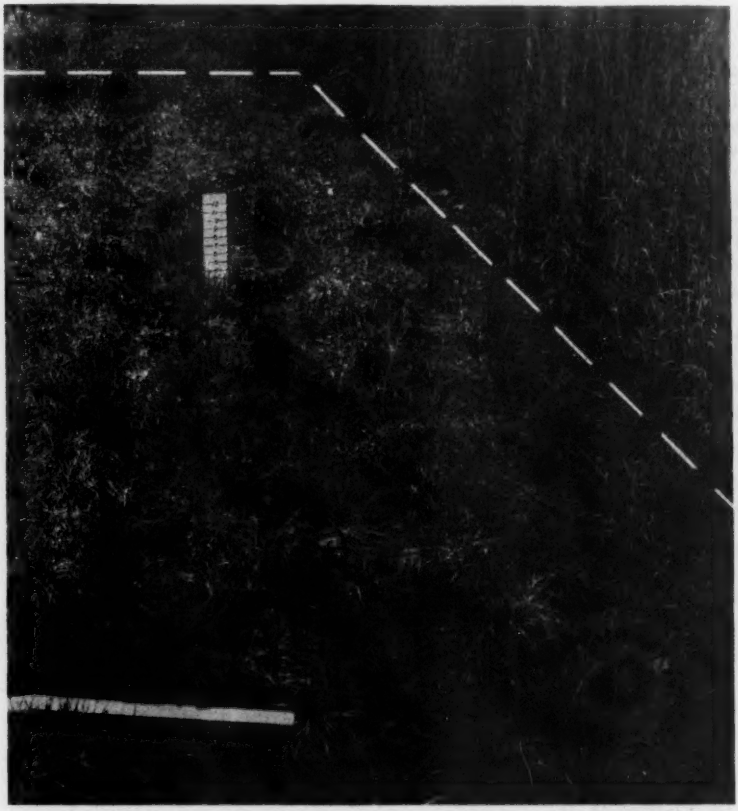

FIGURE 4.—Little bluestem ecotype, origin Schulenburg, Tex., grown in rod-square plot Soil Conservation Service nursery, Manhattan, Kans., showing weak spring growth and considerable winter injury. Photographed May 10, 1941.

TABLE 6.—*Winter injury of little bluestem ecotypes tested at Manhattan, Kans., Soil Conservation Service nursery in rod-square plots, 1940–41*

Accession number	Origin of ecotype	Percentage injury	
		Broadcast	14-inch rows
KG743	Towner, N. Dak.	0	0
KG732	O'Neill, Nebr.	0	0
KG480	Manhattan, Kans.	0	0
KG478	Colony, Kans.	0	0
KG763	Idabel, Okla.	20	30
KG740	Clovis, N. Mex.	50	10
KG750	Gatesville, Tex.	80	40
KG737	Schulenburg, Tex.	75	70

SUMMARY

Little bluestem (*Andropogon scoparius*) plants were grown at the Soil Conservation Service nursery, Manhattan, Kans., from seed obtained from 16 different sources representing different ecotypes. Two series of rod-square plots in which eight ecotypes were represented were observed from 1938 to 1942.

The northern ecotypes were earlier in maturity and lower in forage production than the southern ones. The local ecotypes were intermediate. Higher seed set was obtained with the local ecotypes, which flowered in late August or September. The early northern ones suffered the hot winds of midsummer at flowering time and the later southern ones were sometimes frosted in October.

There were significant differences between ecotypes with regard to time of flowering, dry weight at end of growing season, and height. A high correlation existed between actual flowering date and a theoretical date computed from Hopkins' bioclimatic law which takes into consideration the difference in latitude, longitude, and altitude of the original sources. A highly significant correlation was found between flowering date and dry weight of plant at close of season. The regression coefficient for the effect of flowering date on dry weight of plant was determined.

Winter injury of southern ecotypes was observed in rod-square plots in which eight ecotypes were tested. It appears to be advisable to test ecotypes carefully before seed is transported great distances for large-scale plantings.

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U. S. GOVERNMENT PRINTING OFFICE: 1947